Glassy Electron Behavior in Silicon Transistors

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GLASSES exhibit profound randomness, unlike CRYSTALS, which are noteworthy for possessing highly ordered structures. In addition to ordinary window glass, GLASSES include molecular glasses (polymers and gels), magnetic glasses ("spin glasses"), and electronic glasses. ELECTRONIC GLASSES are known to exist in the still-mysterious high temperature superconductors and scientists at the NATIONAL HIGH MAGNETIC FIELD LABORATORY (NHMFL) recently discovered them in silicon transistors, the basic building blocks of the electronics industry. GLASSES, despite being one of the most common forms of condensed matter, remain one of the most fundamental unsolved problems in condensed matter physics.

The scientists used the magnets at the NHMFL to change the transistor's electrical resistance, the resistance to free flow of electrical current. It was previously known that magnetic fields can have this effect. What is new is that they found a profound change in the RESISTIVE NOISE, or random fluctuations of the resistance. Changes in NOISE result from glassy behavior due to the intricate interplay of mutually-repulsive electrons and the always-present impurities in the transistor. The detailed time dependence of the NOISE gives us a tool to better understand TRANSISTORS and fundamental GLASSY behavior

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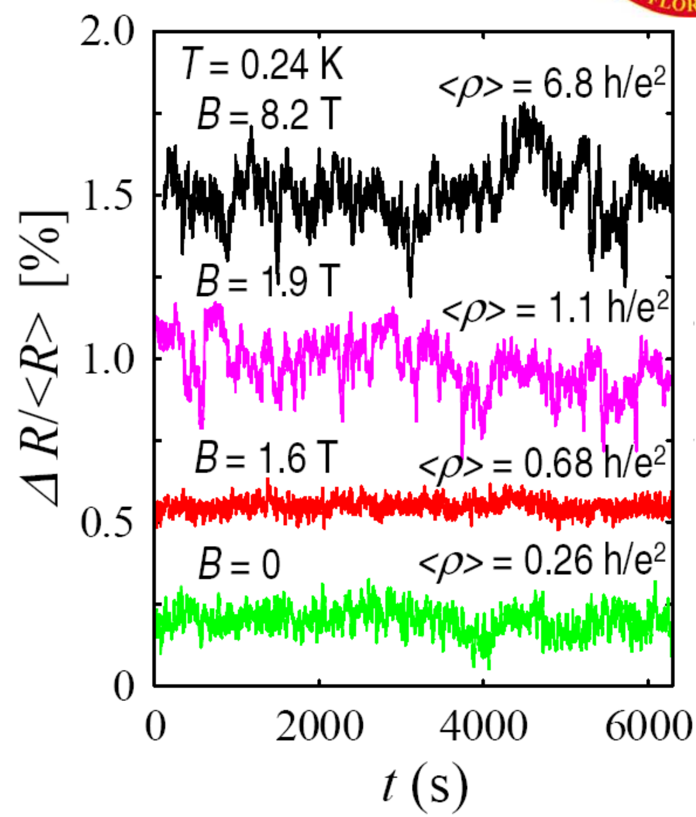

Believe it or not, this RESISTIVE NOISE gives clues about how transistors work at very low temperature, T. The magnetic field, B, dramatically changes the magnitude and frequency distribution of the NOISE. The large and slower fluctuations at higher magnetic field (top two traces) result from collective rearrangements of electrons, a "smoking-gun" characteristic of the GLASSY regime.

We discovered earlier that, under certain conditions, namely when the number of electrons per unit area of the device is relatively small and at temperatures of less than a few tenths of a degree above absolute zero, the current flowing through a Si transistor shows some very slow changes with time, of the order of several hours or even much more. Such slow dynamics is common to all types of glassy materials. Since glassy behavior represents one of the most fundamental, unresolved problems in condensed matter physics, these devices are a convenient tool for studying glassy phenomena. For example, if a sufficiently strong magnetic field is applied parallel to the Si/SiO_2 interface in these transistors, the spins of all electrons will line up and point in the same direction without affecting the motion of the electrons. We have used that technique in this experiment, and monitored the electron dynamics by recording the changes of the current with time. We have established that the slow dynamics persists even when all the electrons' spins point in the same direction. This indicates that it is not the spins, but the electron charges that are responsible for glassy behavior. This information is important in trying to develop a detailed, microscopic understanding of the glassy phenomena. In addition, understanding of such current noise is important for the development of new devices for quantum computing. This work was published in the June 4, 2004 issue of Physical Review Letters.